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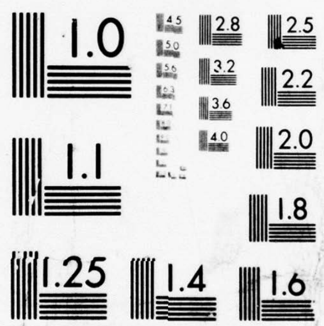

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FOREIGN TECHNOLOGY DIVISION

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EFFECTIVENESS OF USING AERODYNAMIC LIFT FOR LAUNCHING A SPACECRAFT IN THE ATMOSPHERE OF MARS

by

N. M. Ivanov, A. I. Martynov

FOREIGN TECHNOLOGY DIVISION

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EDITED TRANSLATION

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А а	*А а*	A, a	Р р	*Р р*	R, r
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М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

EFFECTIVENESS OF USING AERODYNAMIC LIFT FOR LAUNCHING A SPACECRAFT IN THE ATMOSPHERE OF MARS

N. M. Ivanov and A. I. Martynov

Summary

This report considers two extreme cases of the descent of a launched spacecraft with aerodynamic lift in the atmosphere of Mars: the simplest case in which the launch is realized at a constant lift-drag ratio, and a launch which is more difficult to realize with the optimum control of lift, making it possible to obtain the minimum end velocity for a vehicle with given characteristics. The value of the difference in the end velocities during the

realization of these two types of launch is used to determine which of them is preferable in a specific instance. Numerical results are given.

It is difficult to solve the problem of aerodynamic launching of spacecraft to the surface of Mars because the planet's atmosphere is extremely rarefied. Therefore, it is the most difficult to use ballistic spacecraft, since the value of the effective load on the frontal surface of these launched spacecraft (SA) should not exceed ~70 kg/m² [1, 2]. The introduction of lift makes it possible to considerably facilitate the solution of the problem of aerodynamic launching: to decrease the final velocity V_K - the velocity at the time when the soft landing system is switched on, to increase the load on the frontal surface of the SA, etc.

The effectiveness of the use of aerodynamic lift to launch a spacecraft (KA) in the atmosphere of Mars can be determined by the value of the end velocity to which the spacecraft is braked, since the power plant expends several dozen kilograms of the weight of the fuel and the

structural components of the soft landing system on active braking for every 10 m/s of the increase in velocity V_K.

This study considers two extreme cases of the descent of an SA with aerodynamic lift - the launch which is the simplest to realize, with a constant lift-drag ratio (K = const), and the launch which is more difficult to realize, with the optimum control of lift (K = var), making it possible to obtain the minimum end velocity for an SA with given characteristics. Other conditions being equal, the value of the difference in the end velocities $\delta V_к = (V_к)_{K-const} - (V_к)_{K-var}$ which are reached when using these two types of launch can be used to determine which of them is preferable in each specific instance.

We will consider the case of the entry of a spacecraft into the atmosphere of Mars on a direct Earth-Mars flight trajectory, for which the velocity of entry into the atmosphere of Mars $V_{вх} \approx 6$ km/s. A limitation on the altitude of the spacecraft above the planet's surface is imposed on the launch trajectory:

$$H \geqslant (H_{min})_{доп}. \qquad (1)$$

A "working" model of the atmosphere of Mars [1, 2] was used for simulating the equation of the movement of the center of mass of the SA.

Launch at a Constant Lift-Drag Ratio. We will consider the movement of an SA inside the effective entry corridor. The lower boundary of the effective entry corridor is determined by the minimum altitude of the arbitrary pericenter of the entry trajectory H_{π}^{n} at which it is still possible to satisfy limitation (1) when $K=K_{max}$. The upper boundary is determined from the condition of the capture of the SA by the atmosphere of Mars. Here the spacecraft is considered to be captured by the atmosphere when the maximum flight altitude after initial immersion in the dense layers of the atmosphere does not exceed 100 km.

It should be pointed out that the lower boundary of the effective entry corridor essentially depends on the planned ballistic parameters of the SA [the effective load on its frontal surface $P_x=\frac{G}{c_x S}$, where c_x, S and G are the coefficient of frontal resistance, the area of the midsection, and the weight of the SA (on the Earth), respectively, and the lift-drag ratio of the SA $K_6=\frac{c_y}{c_x}$ at a balancing angle of attack α_6 = const],

and on the minimum permissible altitude $(H_{min})_{доп}$. Here the altitude of the arbitrary pericenter H_{π}^{u} increases with the increase in P_x and $(H_{min})_{доп}$, and with the decrease in $K_б$. Thus, for example, increasing P_x from 200 to 650 kg/m² causes H_{π}^{u} to increase from -270 to -100 km, while increasing $(H_{min})_{доп}$ from three to nine km causes H_{π}^{u} to increase from -230 to -130 km, and decreasing $K_б$ from 0.5 to 0.3 changes H_{π}^{u} from -287 to -113 km (Fig. 1).

Figure 2 gives the dependences of the values of the end velocity on the planned ballistic parameters of the SA (P_x and $K_б$) and on the altitude of the arbitrary pericenter of the entry trajectory. It is evident that for a launch at $K_б$ = const, the value of the end velocity essentially depends on the altitude of the arbitrary pericenter of the entry trajectory, reaching the maximum near the middle of the entry corridor. Thus, for example, for an SA with P_x = 350 kg/m² and $K_б$ = 0.3 ($V_{вх}$ = 6 km/s)

$V_к$ = 630 km/s at $H_{\pi} = H_{\pi}^{u} = -170$ km,

$V_к$ = 740 m/s at $H_{\pi} = H_{\pi}^{u} = -50$ km,

$V_к$ = 760 m/s at $H_к = -80$ km.

We will also point out that when the SA moves at a constant lift-drag ratio, the minimum value of the end velocity is achieved during movement along the lower boundary of the effective entry corridor. Here the maximum dispersion of the value of the end velocity during movement inside the effective entry corridor at $K_б$ = const is 120-150 m/s. As would be expected, increasing the load on the frontal surface and the lift-drag ratio causes the end velocity to increase. Thus, for example, when P_x increases from 200 to 650 kg/m², $V_к$ increases from 650 to 976 m/s, and when $K_б$ changes from 0.3 to 0.5, the value of $V_к$ increases from 760 to 1016 m/s (the maximum values of $V_к$ inside the effective entry corridor are considered).

Optimum Control of End Velocity. In order to determine the optimum law of the control of the "effective " quality $K_{эф} = K_б \cos\gamma$ (γ is the angle of roll of the SA) with the condition of the minimum end launch velocity, the corresponding variation problem was solved.

The plane movement of the center of mass of the SA in the atmosphere of irrotational Mars was examined:

$$\left.\begin{aligned}\dot{V} &= -\frac{\rho V^2 g_3}{2P_x} - g_M(H)\sin\theta;\\ \dot{\theta} &= K_{\text{эф}}\frac{\rho V g_3}{2P_x} - g_M(H)\frac{\cos\theta}{V} + \frac{V\cos\theta}{R+H};\\ \dot{H} &= V\sin\theta.\end{aligned}\right| \quad (2)$$

Here V and H are the flight velocity and altitude; θ is the angle of slope of the SA trajectory to the local horizon; R is the mean radius of Mars; ρ is the density of the atmosphere of Mars; $g_M(H)$ is the acceleration of the force of gravity on Mars; g_3 is the acceleration of the force of gravity on the Earth; and the point designates the derivatives of time t. The value of the effective load on the frontal surface of the SA P_x was considered to be constant over the entire launch trajectory.

The problem was solved with the limitations

$$H_k - H(t) \leqslant 0; \quad (3)$$

$$-K_6 \leqslant K_{\text{эф}} \leqslant K_6 \quad (4)$$

and with the boundary conditions

$$\left.\begin{array}{c} V(t_0)=V_{\text{вх}};\quad \theta(t_0)=\theta_{\text{вх}};\quad H(t_0)=H_{\text{вх}};\quad H(t_{\text{к}})=H_{\text{к}}; \\ t_{\text{к}}-\text{free.} \end{array}\right\} \quad (5)$$

The subscript "0" designates the initial conditions corresponding to the entry of the spacecraft into the atmosphere of Mars.

L. S. Pontryagin's principle of the maximum [3, 4] was used to write the necessary conditions of optimality.

The study conducted showed that there can be two types of optimum control, depending on the parameters of the SA P_x and K_6, and the minimum permissible flight altitude $(H_{\min})_{\text{доп}}$, under identical entry conditions.

The first type of optimum trajectory contains sections of movement along boundary (3). In the iso-altitude section of the trajectory, control is uniquely determined by the condition of the passage of the extremum along boundary (4) and has the form

$$K_{эф}=\left(\frac{1}{\overline{V}^2}-1\right)\frac{2P_x}{g_3\rho_к(R+H_к)}, \text{ where } \overline{V}=\frac{V}{\sqrt{g_M(R+H_к)}}.$$

The trajectory converges with the boundary inside the permissible range of phase coordinates with a value of effective quality of $K_{эф}=+K_6$, which remains constant to the end of the trajectory. It should be pointed out that when there is a horizontal section in the optimum entry trajectory, functional $V_к$ does not depend on the initial conditions V_0, θ_0 and H_0.

The second type of optimum trajectory does not contain an iso-altitude section. The control program is one with single-phase switching of the effective quality from $K_{эф}=-K_6$ to $K_{эф}=+K_6$.

It must be pointed out that decreasing the minimum permissible flight altitude of the SA above the surface of Mars, as well as the load on the frontal surface of the SA and the value of the lift-drag ratio, results in a decrease in the period of time during which the SA moves

along boundary $H=(H_{\min})_{\text{доп}}$. Here for certain types of SA there is an altitude $(H_{\min})_{\text{пред}}$ at which the optimum trajectory does not contain an iso-altitude section when the condition $(H_{\min})_{\text{доп}} \leqslant (H_{\min})_{\text{пред}}$ is satisfied. Thus, for example, for an SA with P_x = 250 kg/m² and $K_б$ = 0.3, the value of $(H_{\min})_{\text{пред}}$ = 27.5 km, while for an SA with P_x = 80 kg/m² and $K_б$ = 0.4, this value is 5.83 km. Here, like before, it was considered that $(H_{\min})_{\text{доп}}=H_{\text{к}}$.

We will once again point out that when the first type of optimum control program (containing an iso-altitude section) is used, the trajectory converges with the boundary inside the permissible region of phase coordinates, i.e., toward an increase in flight altitude.

The comparison of the optimum control program with one which provides for the movement of the SA to the end of the horizontal section at $H=H_{\text{к}}$ shows (Fig. 3) that with the optimum control, the value of the end velocity turns out to be significantly lower, i.e., the gain from optimization is rather great. For example, for an SA with P_x = 350 kg/m², $K_б$ = 0.3 and $H_{\text{к}}$ = 6 km, the loss in the value of the end velocity during flight at $H \equiv H_{\text{к}}$ is 420 s.

We will consider how changing the altitude of the arbitrary pericenter of the entry trajectory, as well as the value of the end velocity, the planned ballistic parameters of the SA (P_x and K_6) and the minimum permissible flight altitude, affect the value of the end velocity during the optimum control of the end launch velocity. The dependences shown in Fig. 4 indicate that the value of the end velocity virtually does not depend on the altitude of the arbitrary pericenter of the entry trajectory within the limits of the effective corridor. As would be expected, increasing the load on the frontal surface and the minimum permissible flight altitude of the SA above the planet's surface and decreasing the lift-drag ratio result in an increase in the end velocity. Thus, for example, increasing P_x from 200 to 500 kg/m² causes $V_к$ to increase from 450 to 726 m/s, increasing $(H_{min})_{доп}$ from 3 to 9 km causes $V_к$ to change from 465 to 656 m/s, and decreasing K_6 from 0.5 to 0.3 causes $V_к$ to increase from 480 to 592 m/s.

Evaluating the Effectiveness of the Optimum Control. The materials obtained above make it possible to evaluate the

effectiveness of the optimum control compared to the program with K_6 = const. Figure 5 shows the dependences of δV_K on P_x and K_6 during the descent of the SA inside the effective entry corridor. It is evident that for an SA with given characteristics, the greatest effect is obtained when the spacecraft moves near the middle of the effective entry corridor, and the smallest - during movement near the lower boundary. Thus, for an SA with P_x = 350 kg/m² and K_6 = 0.3, the maximum gain in δV_K is 170 m/s at H_π = -80 km, and the minimum - 36 m/s at H_π = -170 km. The effect of the use of the optimum equation increases with the increase in K_6, while increasing P_x only slightly affects the value of δV_K. Thus, when K_6 is increased from 0.3 to 0.5, the value of δV_K increases from 170 to 400 m/s, while when P_x changes from 350 to 550 kg/m², it decreases from 170 to 130 m/s.

The studies conducted show that in each specific situation it is necessary to determine the energy expenditures on active braking and on the weight of the launch control system, rather than give preference to the simple or complex type of launch.

Received 19 October 1971

Bibliography

1. Иванов Н. М., Мартынов А. И. О максимально допустимой нагрузке на лобовую поверхность аппаратов, осуществляющих аэродинамический спуск в атмосфере Марса. „Ученые записки ЦАГИ", т. II, № 3, 1971.

2. Иванов Н. М., Мартынов А. И. Об одном алгоритме управления конечной скоростью спуска автоматических аппаратов в атмосфере Марса. „Ученые записки ЦАГИ", т. II, № 5, 1971.

3. Понтрягин Л. С. и др. Математическая теория оптимальных процессов. М., Физматгиз, 1961.

4. Желнин Ю. Н., Шилов А. А. Траектории минимальной дальности при входе космического аппарата в атмосферу Земли со сверхкруговой скоростью. „Ученые записки ЦАГИ", т. I, № 1, 1970.

Fig. 1. KEY: (1) kg/m². (2) Initial conditions.

Fig. 2. KEY: (1) kg/m². (2) m/s.

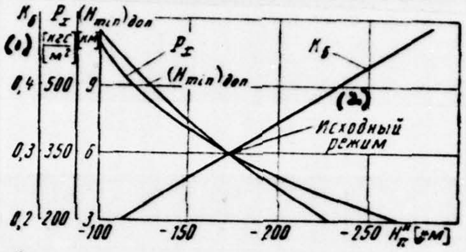


Fig. 1.

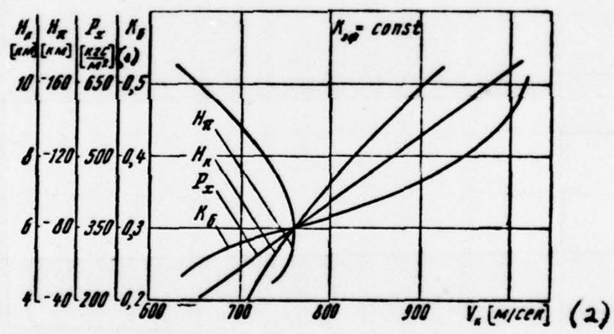


Fig. 2.

Fig. 3. KEY: (1) kg/m². (2) m/s.

Fig. 4. KEY: (1) km/s. (2) kg/m². (3) m/s.

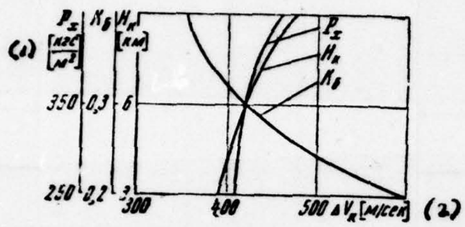


Fig. 3.

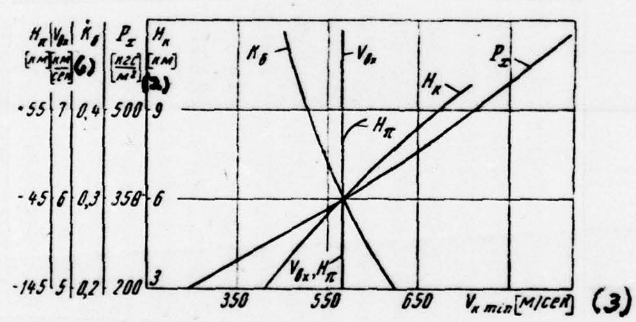
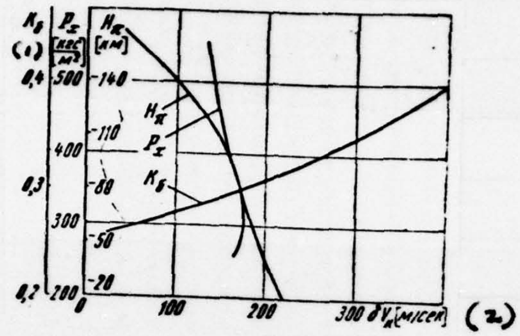


Fig. 4.

Fig. 5. KEY: (1) kg/m². (2) m/s.



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